The Relationship of Bandwidth, Interaction, and Performance in Online Courses: A Study

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Abstract

Although it is often assumed that the larger the bandwidth of the connection to the Internet, the better, few studies have actually been conducted to investigate the impact of various bandwidth connections on student performance in online courses. The goals of this study were to compare student online behaviors under different bandwidth connections and to investigate whether the type of course might be related to the impact of bandwidth for the behaviors. The present findings suggest that, while the use of "dial-up" versus "broadband" was related to some effects of behavioral differences, this relationship was not consistent across courses with different learning tasks. The study suggests that for online courses that are heavily learner-to-learner oriented, special considerations for students using dial-up access be considered.

Introduction

The increasing use of technologies, such as computers, the Internet, the World Wide Web in higher education, is shaping the current generation of distance learning. Among them, broadband technology has had a great impact on distance education due to its drastic increase in availability and use in the past five years. High speed Internet connection provided by the broadband technology does not only have a significant effect on reducing class time allocated by students searching for information on the Internet, but also provide them with more chances of synergy for knowledge construction by facilitating browsing, scanning, searching, transferring, and comparison of information on Web-based courses, and thus makes more online interactions possible.

While the distribution of broadband access has proceeded rapidly, there are still many students taking online classes that are utilizing the dial-up method to access the Web and the online courses. This may be because they cannot pay for the higher cost of broadband or because this service is not available where they live. Accessing an online class at dial-up speeds hampers the delivery of sound, video, and graphics and creates a divide among students. In order to reduce the inequality between bandwidth usages in students' method of accessing to the online courses, some online course providers restrict their users to only those who can access the course via broadband, whereas others use only text and simple graphics so that the lowest bandwidth can be accommodated. However, most institutions have to embrace the difference while students access

to the online courses using either dial-up or broadband. This creates unique learning situations compared to former learning contexts, and at the same time, brings more complexity in educational assessment. To our knowledge, there is almost no research on the impact of bandwidth on student behavior and performance.

Relevant literature

1. Dial-up Connection and Broadband

Bandwidth is the capacity of information carriage in unit time which directly affects the flow size and flow rate of the data transfer on the Internet. "Dial-up", or narrowband Internet access, offers access through traditional telephone lines at speeds of between 28 and 56 kilobits per second (Kbps) (or 53Kbps set by current FCC regulations). The broadband Internet access or high-speed Internet access offers connection at 200 Kbps or higher through a variety of transmission media, including Digital Subscriber Line (DSL), Cable Modem, Wireless, Satellite, Optical Fiber, and Power Line. Narrow bandwidth is most often utilized for text-based information, as congestion is easy to occur if workload is over the capacity. Broad bandwidth, which has high transmission capacity and is much faster than a 56K modem, allows users to send and receive data in terms of megabits, or millions of bits per second (Mbps) and makes the use of large files, real-time audio, and video transfer possible.

Worldwide broadband penetration has increased at a compound annual growth rate (CAGR) of 155 percent from 1999 till the end of 2004. In the United States, the number of residential broadband users increased the highest ever by 36 percent in 2004, accounting for more than half of the total residential online users. The number of users migrating from dial-up to broadband continues to grow, reaching at 58.82 percent in May 2005, and the momentum is supposed to continue through the end of the decade (Point Topic Ltd., 2005).

2. Speed and Performance

Speed has been considered as one of the highest rated problems in using the Web (Kehoe, Pitkow, Sutton, Aggarwal, & Rogers, 1998; Lightner, Bose, & Salvendy, 1996). Slow system response may lead to both serious psychological and economical consequences. In some cases, performance declined when delays exceeded only 1 second (Thadhani, 1981), and 2 seconds delay time is regarded as loss of conversational nature (Miller, 1968). Delay of 8 seconds is commonly regarded as the threshold for adverse psychological and performance consequences (Kuhmann, 1989; Ramsay, Barbesi, & Preece, 1998; Shneiderman, 1998). The anxiety and stress characterized by increased heartbeat, respiratory rate, blood pressure or perspiration of users due to extended waiting are easily detectable. Lazarus and Flokman (1984) believed that these negative symptoms are due to the general sense of waste induced by idleness and by the uncertainty associated with the total waiting time.

While improving page load speeds from 8 seconds to 2-5 seconds doubles site traffic (Wonnacott, 2000), slow response time means reduced level of trust and causes a loss of traffic as users seek alternatives (Hoxmeier & DeCesare, 2000; Nielsen, 2000). Both the actual and the perceived waiting are the top reasons that lead to user dissatisfaction (Bickford, 1999; Hornik, 1984; Katz, Larson, & Larson, 1991). The financial loss as the result of delay can be very high. A study by Zona (1999) shows that over one third of the Web users may simply give up trying to buy an item over the Internet after encountering excessive delays, resulting in the estimated loss of as much as $4.35 billion in e-commerce sales each year.

Several studies conducted in laboratory situations confirmed that there is a linear relationship

between speed and user performance (Bergman, Brinkman, & Koelega, 1981; Dannenbring, 1984; Doherty & Kelisky, 1979; Grossberg & Yntema, 1969; Morfield, Wlesen, Goodman, & Spence, 1978; Martin & Corl, 1986; Thadhani, 1981). However, these studies were conducted on tasks that are deemed as rather simple (Butler, 1983), and the results may not be transferable to online courses. A limited number of studies on the effects of download speed on performance that involves more complex tasks yielded mixed results. A study conducted by Turner and colleagues (Turner, Kaske, & Baker, 1990) showed that though subjects searching at 2400 baud rate did better than those searching at 300 baud rate for the same assigned online tasks, the difference was not significant when subjects' search experience is considered.

3. Bandwidth and Media Study

Bandwidth affects types of medium that could be applied for instructional design, and thus determines what kinds of interaction could be carried out, and how the interactions could be carried out. Conceptually, people tend to conclude that lower bandwidth of collaboration channels creates disadvantages for users because bandwidth or capacities of transmitting information in each communication medium determine the effectiveness of networked collaboration in learning and problem solving. They believe that users' ability to address uncertainty and acquire information is severely limited because nonverbal and contextual cues are reduced or eliminated. For example, early researchers argued that presence is diminished by text-based computer-mediated communication because it is devoid of visual and vocal cues that higher-bandwidth and face-to-face systems provide. A conservative theory of Short, Williams, and Christie (1976) also argued that involvement, warmth, and immediacy that communicators experience during interaction may be limited by bandwidth, or cue-carrying capacity of the system. This social presence theory along with media richness theory (Daft & Lengel, 1986) and task-media fitness theory (McGrath & Hollingshead, 1994) all argued that the bandwidth or capacities of transmitting information in each communication medium determine the effectiveness of networked collaboration in learning and problem solving.

However, there are researchers who have challenged this contention, arguing that behaviors of online learners are amenable and spontaneously adaptable to the social communication that takes place (Fulk, Schmitz, & Steinfield, 1990). They pointed out that these early theories emphasized channel effects but failed to consider the active role of individuals in the communication process. A study conducted on two groups of students assigned to either asynchronous text-based computer conferencing system or face-to-face conventional classroom setting on a discussion of three decision-making tasks over six weeks found no significant differences between the two groups (Walther & Burgoon, 1992). To date, empirical studies have found that bandwidth-constrained environments do not necessarily have a negative impact on user's educational experience (Dennis & Kinney, 1998; Ghinea & Chen, 2003).

4. Bandwidth and Online Interaction

Interaction is regarded as an important component of successful learning (Kearsley, 1995; Keegan, 1988; Thompson, 1990). Either in the form of learner's direct engagement with the course content through independent study or communication with the instructor or other students during the online study, interaction has been found to contribute to both online learning achievement and student satisfaction (Fulford & Zhang, 1993; Kearsley, 1995; Keegan, 1988; Kirby, 1999; Zhang & Fulford, 1994; Swan, 2001).

Moore (1989) suggested that effective distance education courses include all members of the learning community consisting of different types of interaction, and he defined three categories:

learner—content, learner—instructor, and learner—learner interactions, with each having different effects on learning performance. Later, learner—interface interaction was added as a type for online educational environments, which emphasizes the interaction that takes place between the learner and the technology (Hillman, Willis, & Gunawardena, 1994). These four types of interaction are not mutually exclusive but may overlap in online learning (Kirby, 1999). Among many developed models of interaction, Moore's three types of interaction construct is one of the most influential. The three types of interaction are described below.

Learner—content interaction results from student studying the content through participating in various class activities. The main function of education is to engage the learner with the content in a planned process. According to Moore, it is "a defining characteristic of education" because it changes learners' behavior toward an educational goal (p. 2).

Learner—instructor interaction occurs between students and instructors, while the instructors stimulate and guide learners' engagement with the subject content. The importance of learner —instructor interaction has been widely acknowledged both in online and traditional face-to-face learning environment (Garrison, 1990; Holmberg, 1995; Moore & Kearsley, 1996; Muirhead, 2001).

Learner—learner interaction occurs among students of an online environment with or without the presence of instructors. Interaction among students is helpful for both pedagogical reasons because exchange of ideas of learners could promote understanding of the content and building an online learning community that supports the sharing of goals, interests, and knowledge among learners. According to Moore, *learner—learner* interaction is "sometimes an extremely valuable resource for teaching, and sometimes even essential" (p. 4). Empirical evidence suggests that interaction among students is one of the most influential features of online courses (Swan, Shea, Fredericksen, Pickett, Pelz, & Maher, 2000), and it is positively correlated with student's satisfaction and performance with their online learning (Gilbert & Moore, 1998; Moore & Kearsley, 1996; Picciano, 1998; Rourke & Anderson, 2002; Soo & Bonk, 1998; Swan, 2001).

Moore's theoretical framework of interaction has been investigated in several online studies on learning outcomes and student satisfaction (Chen, 2001; Kelsey, & D'souza, 2004; Sherry, Fulford, & Zhang, 1998; Swan, 2001). However, there is a paucity of research on Moore's typology of interaction with the consideration of either the course design or delivery, where learning tasks, content-structure, and technological support are concerned. Researchers believe that these aspects are components in distance learning studies that define the nature of the online learning environment within which online interaction is carried out. For example, Garrison (1999) regarded the transactional nature of the relationship between instructor, learner, and content which is of significance to the learning experience as coming from the design of the educational content.

Moreover, user online activity studies concerning different bandwidth access in academic environment is scarce. One study conducted by an ISP (Newman, 2001) indicated that people using high-speed connections usually spent more time online and were anxious to update the applications. A study on detecting difference of time spent between broadband users with narrowband users conducted by Berchtold and colleagues (2001) found that users spend 27 percent more time online than when they only had narrowband access. They also found that these users spent more time on email, chat, and downloading music, and there was an increased use of game sites when they use broadband. Though there are indications that broadband and dial-up users differ in their behaviors, results of these studies tend to show that the effects were not statistically significant (Rappoport, Kridel, & Taylor, 2002).

With these understandings, we suggest that, there is no doubt that future development of broadband will open opportunities for course designers to create more engaging learning contexts, and it can be assumed that more bandwidth is better, however, the advantages of more bandwidth for the success of Web-based systems might not be apparent to us until user needs to which they apply are identified and targeted. This requires in depth investigations in real online learning situations. The goals of this study therefore were to investigate whether accessing an online class through higher bandwidth alters the online learning experience and whether the interaction emphasized in the course design influences the impact of bandwidth.

Research Questions and Hypotheses

More specifically, the study investigated whether actual use of bandwidth impacted student behaviors in online classes in general and whether the impact would be differential depending upon where the course fell in two of Moore's interaction dyads, *learner—content* and *learner—learner* interactions. The hypotheses tested were:

1) There will be no relationship between level of bandwidth access (dial-up vs. broadband) and student online interactions/behaviors (number of online sessions, total time connected, email read, email sent, discussion read, and discussion posted, etc).

2) There will be no online behavioral difference due to different level of bandwidth access (dial-up vs. broadband) in the online course requiring rich *learner—content* interaction.

3) There will be no online behavioral difference due to different level of bandwidth access (dial-up vs. broadband) in the online course requiring rich *learner—learner* interaction.

Methodology

Participants

All participants of this study were graduate students pursuing a master degree in Library and Information Sciences at a major university in Texas. Students identified how they accessed the course, and this choice was used to place them into two groups. One group of students used dial-up method, and their online speed was at a maximum 53 kbps; the other group of students had a high bandwidth connection through DSL, Cable, or other broadband methods. A questionnaire was administered through email at the end of each class. Participation was not mandatory, so not all students who enrolled in these courses actually completed the questionnaire. The response rate was more than 90 percent in each of the courses, with a total enrollment of 330.

Courses

Data were collected from two graduate courses delivered using the Learning Content Management System (LMS), WebCT (Campus Edition and later Vista Edition in the second and third iterations of investigation). The first course was a required introductory course in the Masters of Library and Information Sciences. This course was presented in a blended format in which the students met for a full day on campus followed by a semester pursuing the course online. The second course was a graduate research methodology class provided by the same department and was offered 100 percent online.

The online graduate introductory course utilized predominantly *learner—learner* interaction in

the form of threaded discussions around common questions proposed by the teacher. The content presented in the course was limited to a set of reading resources and discussion questions.

The graduate research methodology course was predominantly *learner—content* oriented. There was a full set of instructional materials mounted within the LMS with detailed instructions on assignments and self-tests for most of the modules of content provided. A CD-ROM was provided containing 130 video clips that varied in length from 20 seconds to 7 minutes. These clips were of the faculty member demonstrating concepts.

Design

The study covers a period from June 2003 to August 2005, with a total participant of 304 graduate students. There were three iterations of data collections and analyses. The first was during the summer of 2003 and involved both the online graduate introductory course and the online graduate research methodology course. These were both delivered using WebCT Campus Edition. The second and third iterations involved only the online graduate introductory course using the Vista Edition of WebCT.

A single factor (bandwidth), two-level design (narrow vs. broadband) was used for each of the two types of courses (*learner—learner* and *learner—content*) in the study. The independent variable is bandwidth; the dependent variables are the amount of online course content read, number of discussion posting read, and number of discussion posted for the first data analysis of both courses. For the second and third data analyses, which were performed only on the online graduate introductory course, number of times the course was accessed, total time spent in the online course, discussion posting read, discussion posted, and email activities were analyzed.

Data collection

A questionnaire was administrated at the end of each of the courses for the three data analyses to gather information on student bandwidth use, perception of connection speed, and possible technical problems encountered. Detailed statistics on student online learning activities, such as online course content reading (Hits), discussion posting read (Posting_read), and actual discussion posted (Postings) were collected through WebCT and later Vista logs. Times of access to the course (Session), total time spent on the course (Time), e-mail read (ReadM), and sent (SendM) were additionally collected for the second and third data analyses.

Results

To assess the correlation between bandwidth use and student online interactivities, a series of one-way analyses of variance (ANOVA) were performed on SPSS (the Statistical Package for the Social Sciences) version 12.0.

First Iteration Data Analysis: Both Courses Taught in WebCT CE

For the first iteration data analysis, total number of student is reduced from 101 to 99 for the online graduate introductory course and from 50 to 48 for the online graduate research methodology course due to high kurtosis on the dependent variable of postings of these students. Mean levels of perceived online student activities were compared across two groups of student with different bandwidth connections. Tables 1 and 2 present the descriptive statistics of the online graduate introductory course and online research methodology course, separately.

Table 1

*Descriptive Statistics on Online Graduate Introductory Course (*n = *99)*

Variable	N/B*	N	Mean	Std. Deviation	Std. Error
Hits	1.00	34	406.1176	155.10129	26.59965
	2.00	65	472.7077	203.05131	25.18542
Posting_read	1.00	34	206.0588	122.23696	20.96347
	2.00	65	265.5692	121.61504	15.08449
Postings	1.00	34	19.2941	7.66547	1.31462
	2.00	65	22.4000	10.40252	1.29027

N/B* : 1= Dial-up; 2 = Broadband.

Table 2

*Descriptive Statistics on Online Graduate Research Methodology Course (*n = *48)*

Variable	N/B*	N	Mean	Std. Deviation	Std. Error
Hits	1.00	12	1263.7500	452.59617	130.65326
	2.00	36	1262.9167	621.90731	103.65122
Posting_read	1.00	12	405.0000	121.07548	34.95148
	2.00	36	393.3333	174.13837	29.02306
Postings	1.00	12	51.5833	13.72097	3.96090
	2.00	36	48.0556	15.60759	2.60126

N/B* : 1= Dial-up; 2 = Broadband.

Homogeneity test of variance over the variables show no indication of violation for the online graduate introductory course ($n = 99$) (refer to Table 3). ANOVA results indicate that the bandwidth use is significantly correlated with online discussion posting read, $F(1, 97) = 5.327$, $p < .023$, $\mu 2 = .0521$, indicating that students who used broadband read significantly more postings on the discussion board than those students who used narrowband connection; but the results show barely statistic significant on online content reading ($p = 0.98$, $\mu 2 = .0281$) and actual discussion posted ($p = .128$, $\mu 2 = .0237$).

The results also show that there is no indication of statistical significant influence of bandwidth use on any student online activities on online content reading, $F(1, 46) = .000$, $p = 0.997$, online discussion posting read, $F(1, 46) = .046$, $p = .831$, and actual discussion posted, $F(1, 46) = .486$, $p = 0.489$, for the online research methodology course (refer to Table 5).

Table 3

*Test of Homogeneity of Variances (*n = *99)*

Variable	Levene Statistic	*df1*	*df2*	Sig.
Hits	2.316	1	97	.131
Posting_read	.004	1	97	.947
Postings	3.618	1	97	.060

Table 4

*ANOVA Results on Online Graduate Introductory Course (*n = *99)*

Variable	Source of Variation	Sum of Squares	*df*	Mean Square	F	*p*-Value
Hits	Between Groups	98986.439	1	98986.439	2.797	.098
	Within Groups	3432570.976	97	35387.330		
	Total	3531557.414	98			
Posting_read	Between Groups	79057.472	1	79057.472	5.327	.023
	Within Groups	1439655.821	97	14841.813		
	Total	1518713.293	98			
Postings	Between Groups	215.341	1	215.341	2.356	.128
	Within Groups	8864.659	97	91.388		
	Total	9080.000	98			

Table 5

*ANOVA Results on Online Graduate Research Methodology Course (*n = *48)*

Variable	Source Of Variation	Sum of Squares	*df*	Mean Square	F	*p*-Value
Hits	Between Groups	6.250	1	6.250	.000	.997
	Within Groups	15790181.000	46	343264.804		
	Total	15790187.250	47			
Posting_read	Between Groups	1225.000	1	1225.000	.046	.831
	Within Groups	1222598.000	46	26578.217		
	Total	1223823.000	47			
Postings	Between Groups	112.007	1	112.007	.486	.489
	Within Groups	10596.806	46	230.365		
	Total	10708.812	47			

Second Iteration Data Analysis: Introductory Course Taught in WebCT Vista

For the second iteration data analysis, which involved only the online introductory graduate course, the total number of students is 48. Mean levels of perceived online student activities were compared across two groups of students with different bandwidth connections. Table 6 presents the descriptive statistics of the online graduate introductory course analyzed. It shows that the

means of the online activities (session, total time online, e-mail read, sent, read of discussion postings, and actual discussion posted) of students using broadband are all higher than those using narrowband, indicating more student online activities. This suggests that bandwidth does quantitatively and positively influence student online activities on WebCT Vista for the online graduate introductory course in general.

Table 6

*Descriptive Statistics on Online Graduate Introductory Course (*n = *48)*

Variable	N/B*	N	Mean	Std. Deviation	Std. Error
Session	1.00	7	79.4286	20.18958	7.63094
	2.00	41	101.2683	39.30778	6.13884
Time	1.00	7	15.0343	5.54283	2.09499
	2.00	41	22.8237	7.48479	1.16893
ReadM	1.00	7	35.7143	17.13393	6.47602
	2.00	41	42.4634	17.88449	2.79309
SendM	1.00	7	9.0000	6.80686	2.57275
	2.00	41	10.0488	6.45349	1.00787
ReadD	1.00	7	304.5714	230.37495	87.07355
	2.00	41	718.6585	486.09169	75.91477
PostD	1.00	7	18.4286	4.96176	1.87537
	2.00	41	24.9024	7.68051	1.19949

N/B* : 1= Dial-up; 2 = Broadband.

Homogeneity test of variance over the variables shows no indication of violation ($n = 48$) (refer to Table 7). ANOVA results indicate that bandwidth use is significantly correlated with total time student spent online, $F (1, 46) = 6.881$, $p < .012$, $\mu 2 = .130$, indicating that students who used broadband spent significantly more time online on the course than those who used narrowband. The results also show statistic significant on actual discussion posted, $F (1, 46) = 4.827$, $p < .033$, $\mu 2 = .095$; statistically significant on discussion posting read, $F (1, 46) = 4.597$, $p < .037$, $\mu 2 = .091$. These also indicate that students who used broadband wrote more discussion postings and viewed more online discussion postings than those who used narrowband. However, there are no indications of statistical significant influence either on e-mail activities or frequency (session) of access to the online course (refer to Table 8).

Table 7

*Test of Homogeneity of Variances (*n = *48)*

Variable	Levene Statistic	*df1*	*df2*	Sig.
Session	3.283	1	46	.077
Time	.864	1	46	.357
ReadM	.167	1	46	.685
SendM	.059	1	46	.809
Posting_read	3.378	1	46	.073
Postings	2.380	1	46	.130

Table 8

*ANOVA Results on Online Graduate Introductory Course (*n = *48)*

Variable	Source of Variation	Sum of Squares	*df*	Mean Square	F	*p*-Value
Session	Between Groups	2851.904	1	2851.904	2.042	.160
	Within Groups	64249.763	46	1396.734		
	Total	67101.667	47			
Time	Between Groups	362.782	1	362.782	6.881	.012
	Within Groups	2425.219	46	52.722		
	Total	2788.001	47			
ReadM	Between Groups	272.355	1	272.355	.861	.358
	Within Groups	14555.624	46	316.427		
	Total	14827.979	47			
SendM	Between Groups	6.577	1	6.577	.156	.695
	Within Groups	1943.902	46	42.259		
	Total	1950.479	47			
Posting_read	Between Groups	1025236.545	1	1025236.545	4.827	.033
	Within Groups	9769840.934	46	212387.846		
	Total	10795077.479	47			
Postings	Between Groups	250.593	1	250.593	4.597	.037
	Within Groups	2507.324	46	54.507		
	Total	2757.917	47			

Third Iteration Data Analysis: Introductory Course Taught in WebCT Vista

For the third iteration data analysis, which again involved only the online graduate introductory course, the total of number of student is 105. Mean levels of perceived online student activities were compared across two groups of student with different bandwidth methods. Table 9 presents the descriptive statistics of the online graduate introductory course analyzed. It shows that the means of the online activities (session, total time spent online, e-mail read, sent, and actual discussion posted) of the students using broadband connection are higher than those of students using narrowband, except for the online discussion postings read. This suggests that bandwidth does quantitatively and positively influence student online activities on Vista on the online graduate introductory course in general.

Table 9

*Descriptive Statistics on Online Graduate Introductory Course (*n = *105)*

Variable	N/B*	N	Mean	Std. Deviation	Std. Error	Maximum
Session	1.00	19	61.2632	22.44460	5.14915	115.00
	2.00	86	77.3372	32.09787	3.46120	178.00
	Total	105	74.4286	31.11111	3.03613	178.00
Time	1.00	19	21.13526	9.731863	2.232643	49.220
	2.00	86	27.94674	15.370275	1.657419	90.080
	Total	105	26.71419	14.711205	1.435667	90.080
ReadM	1.00	19	40.2105	16.95936	3.89074	84.00
	2.00	86	43.9302	22.91149	2.47061	134.00
	Total	105	43.2571	21.92909	2.14006	134.00
SendM	1.00	19	10.2632	7.30177	1.67514	30.00
	2.00	86	10.7791	7.57768	.81712	42.00
	Total	105	10.6857	7.49656	.73159	42.00
Posting_read	1.00	19	2649.3158	3490.79402	800.84307	11919.00
	2.00	86	2600.1163	2279.34750	245.78836	10374.00
	Total	105	2609.0190	2521.04673	246.02897	11919.00
Postings	1.00	19	30.4737	12.92443	2.96507	67.00
	2.00	86	33.9186	12.61019	1.35979	72.00
	Total	105	33.2952	12.67487	1.23694	72.00

N/B* : 1= Dial-up; 2 = Broadband.

Homogeneity test of variance over the variables shows moderate indication of violation (n = 105) on session and discussion postings read (refer to Table 10). ANOVA results indicate that bandwidth use is significantly correlated with session of student access to the online course on Vista, F (1, 103) = 4.285, $p < .041$, $\mu 2 = .040$, indicating that students who used broadband method significantly accessed more frequently to the online course than those who used narrowband connection. The results also show barely statistic significant difference in total time spent on the online course, F (1, 103) = 3.414, $p < .068$, $\mu 2 = .0331$, indicating that students who used broadband connection spent more time on the online course than those who use narrowband. There are, however, no indications of statistical significant influence either on e-mail activities or discussion postings activities for the online graduate introductory course (refer to Table 11).

Table 10

*Test of Homogeneity of Variances (*n = *105)*

Variable	Levene Statistic	*df1*	*df2*	Sig.
Session	4.112	1	103	.045
Time	3.026	1	103	.085
ReadM	1.520	1	103	.220
SendM	.117	1	103	.733
Posting_read	5.030	1	103	.027
Postings	.028	1	103	.868

Table 11

*ANOVA Results on Online Graduate Introductory Course (*n = *105)*

Variable	N/B*	Sum of Squares	*df*	Mean Square	F	*p*-Value
Session	Between Groups	4020.809	1	4020.809	4.285	.041
	Within Groups	96640.905	103	938.261		
	Total	100661.714	104			
Time	Between Groups	722.014	1	722.014	3.414	.068
	Within Groups	21785.619	103	211.511		
	Total	22507.634	104			
ReadM	Between Groups	215.318	1	215.318	.445	.506
	Within Groups	49796.739	103	483.463		
	Total	50012.057	104			
SendM	Between Groups	4.142	1	4.142	.073	.787
	Within Groups	5840.487	103	56.704		
	Total	5844.629	104			
Posting_read	Between Groups	37669.019	1	37669.019	.006	.939
	Within Groups	660952698.942	103	6417016.495		
	Total	660990367.962	104			
Postings	Between Groups	184.681	1	184.681	1.151	.286
	Within Groups	16523.167	103	160.419		
	Total	16707.848	104			

N/B* : 1= Dial-up; 2 = Broadband.

To sum up, results of the three iteration data analyses show occasions of statistically significant correlations between bandwidth access methods with online student behaviors on the online graduate introductory course. For the first iteration data analysis, students using broadband read significantly more online discussion postings in the online graduate introductory course. The second iteration data analysis shows that students who used broadband spent significantly more time in the online course and read more discussion postings as well as posted more discussion items in the online graduate introductory course than those who used narrowband. The third iteration data analysis shows that students who used broadband more frequently accessed the online course than those who used narrowband and spent considerably more total time on the online learning in the online graduate introductory course. For the online graduate research methodology course, there was no statistically significant difference on all activities by the two groups of student. In fact, there was little or no difference in the variables measured between the students who accessed the class via dial-up versus broadband.

From the results, we conclude that:

- There was some evidence of a relationship between level of bandwidth access and student interactions and behaviors (hypothesis 1).
- This relationship was not found in the course that emphasized *learner—content interaction* (hypothesis 2).
- The relationship did occur in the class which was heavily weighted toward *learner —learner interaction* (hypothesis 3).

Discussion

The relationship between speed and performance that has been demonstrated by studies conducted in laboratory environments was not totally confirmed in this study. Moore's interaction model is useful in explaining the inconsistency of the relationship.

Learner—Learner Interaction

The course (the graduate introductory course) in which students spent most of their online time interacting with each other showed the largest and, in fact, only relationship between bandwidth and behavior. In this class, students were required to participate in discussions around a series of questions that were supplemented by online readings. There was a minimum number of discussion postings required in the class as well as a minimum number of readings. Evidently, students who used dial-up access were less likely to go beyond the minimum postings to interact more broadly with their fellow students. Why might this have occurred? While the slower bandwidth did lengthen page refresh rates, the dial-up students could have interacted as heavily as the broadband students simply by staying online longer. However, in fact, the students who used dial-up spent less time (significantly less in the second iteration of the study) than those students who accessed the course via broadband. The finding does confirm the result of Berchtold and colleagues (2001).

Learner—Content Interaction

Why was the impact of bandwidth in the courses that emphasized learner—content interaction almost non-existent? Most likely, the students spent enough time on each content segment that the screen refresh rate did not have an impact. In addition, a CD-ROM was supplied that provided the high bandwidth portion of the content off-line.

Conclusions and Recommendations

Until broadband access is truly ubiquitous, those who offer online courses and programs will need to make decisions regarding course design and access policies. This was an exploratory study limited to *post hoc* analysis of existing data and to the examination of user behavior only. Despite these limitations, it is apparent that viewing the impact of the choice of narrow versus broadband access is not as simple as it might have appeared. Our results show that bandwidth has the most impact when interaction among student (or *learner—learner* interaction) represented the major behavioral requirements in the course, and it had the least when the main function of the Web-based portion of the course was acquisition of large chunks of content (or has a focus on *learner—content* interaction).

Instructional designers and instructors should integrate interaction into online courses to ensure success of online learning. Whether the course design calls for an emphasis on learner—content interaction or learner—learner interaction, the impact of the bandwidth utilized by the students to access the course should be considered. Our first recommendation is that more studies of the problem should be carried out. Studies utilizing the current learning management systems should consider defining the courses using a wide range of learner—instructor—content—interface interactions with consideration of the learning context. Attention should be paid to determine the range of activities in which students are engaged in while logged into the class, including activities that are not class related.

For courses that are heavily learner—content oriented and do not utilize a large amount of bandwidth-heavy applications, having students in the class who are accessing it via dial-up may

not pose a problem. In this type of class, course designers should consider providing student video, audio, and sophisticated graphics "off-line".

If a course requires a significant amount of interaction among students, those who are delivering the course may want to urge students to utilize broadband access when available so the access does not impair the learning experience. They may also consider strategies to minimize the number of postings that must be read by grouping students into discussion "subgroups".

In a word, this study lays the groundwork for more in-depth investigations of the effects of bandwidth access on student online behaviors. With the increasing availability of bandwidth as well as other technologies, major transformation of education becomes possible; the challenge we are facing therefore is to fully exploit these new technologies to support the design of online instruction.

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